



# ROBOTIC SYSTEMS



Michigan Chapter  
**NDIA**  
National Defense Industrial Association

## OPTIMAL TIME AND ENERGY EFFICIENCY IN LEGGED ROBOTICS

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# OPTIMIZATION

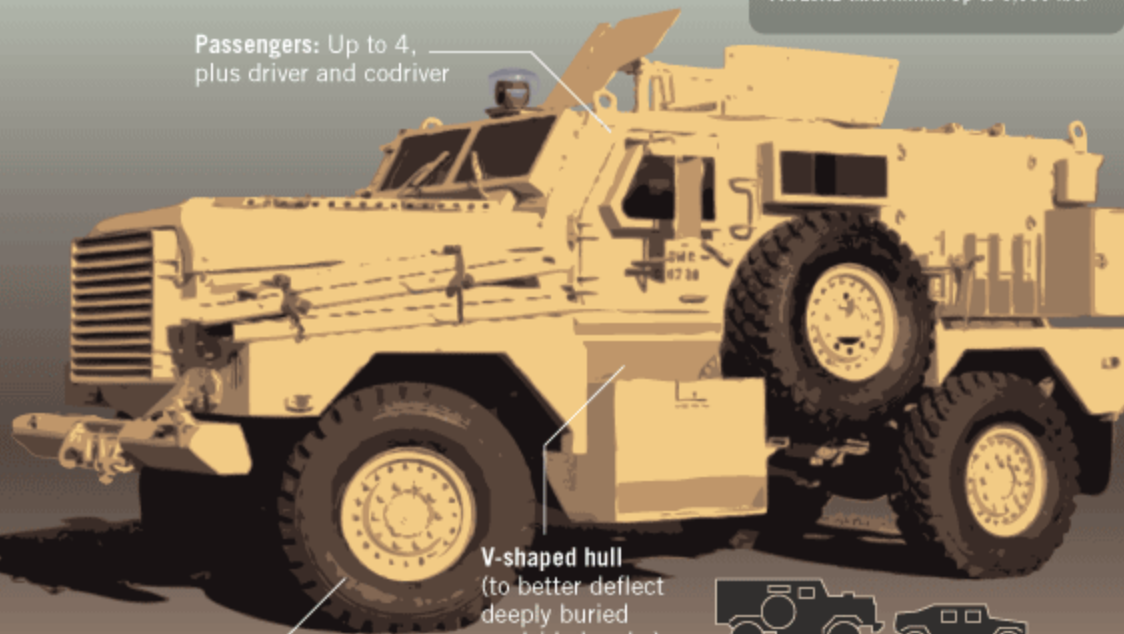
# ROBOTIC SYSTEMS

## Mine-Resistant, Ambush-Protected Vehicle (MRAP)

MRAPs can weigh two to five times as much as humvees, prompting concerns that they could cause some bridges to collapse. But sitting up high allows soldiers to see more.

HORSEPOWER ..... 330 at 2,400 rpm  
RANGE ..... 420 miles  
HEIGHT ..... Approx. 104 inches  
WIDTH ..... 108 inches  
LENGTH OVERALL ..... 233 inches  
WEIGHT ..... 32,000 lbs.  
PAYLOAD MAX ..... Up to 6,000 lbs.

Passengers: Up to 4,  
plus driver and codriver

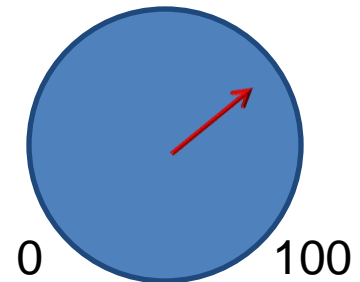


V-shaped hull  
(to better deflect  
deeply buried  
roadside bombs)

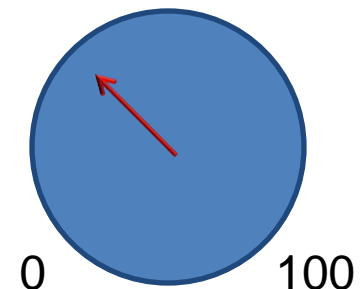
Run-flat tires



HUMVEE



SURVIVABILITY

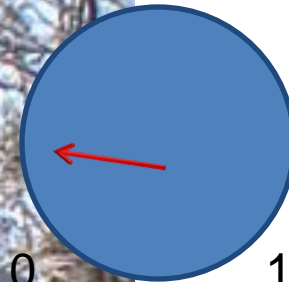


MOBILITY



# OPTIMIZATION

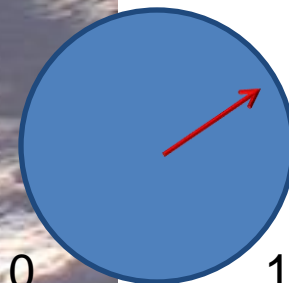
# ROBOTIC SYSTEMS



0

100

EFFICIENCY



0

100

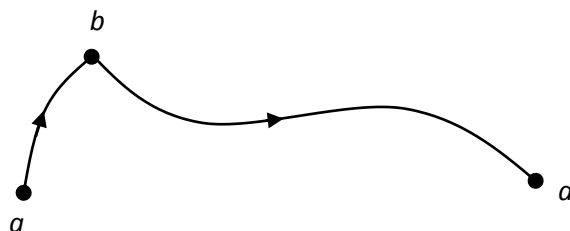
MOBILITY

- PRINCIPLE OF OPTIMALITY
- OPTIMAL CONTROL
  - POYNTRYAGIN'S MAXIMUM PRINCIPLE
  - DYNAMIC PROGRAMMING
- EXAMPLE: SWITCHING CURVE IN POWERED PENDULUM
- HARDWARE IMPLEMENTATION
- CONCLUSIONS & FUTURE WORK

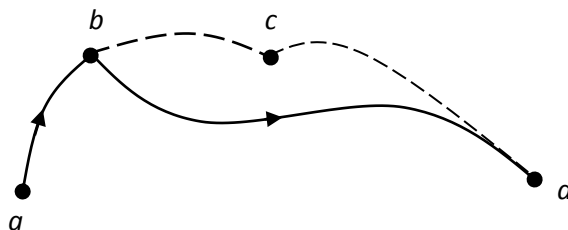


# PRINCIPLE OF OPTIMALITY

## ROBOTIC SYSTEMS



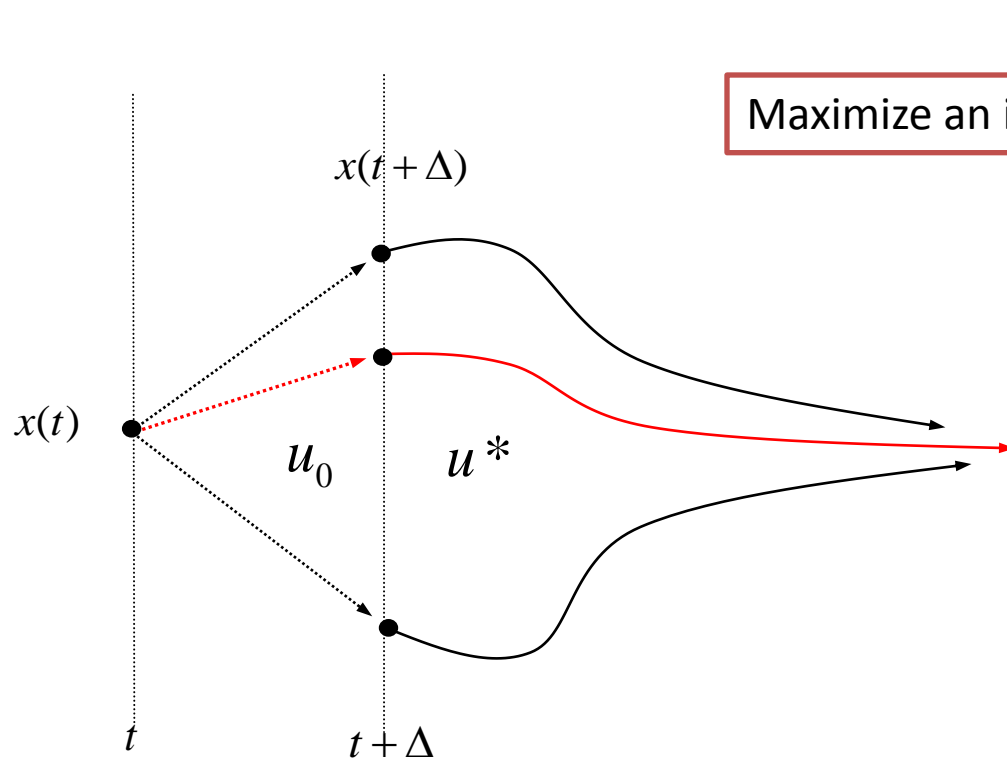
If  $a-b-d$  is the optimal path from  $a$  to  $d$ , then  $b-d$  is the optimal path from  $b$  to  $d$ .





# POYNTRYGIN MAXIMUM PRINCIPLE

# ROBOTIC SYSTEMS

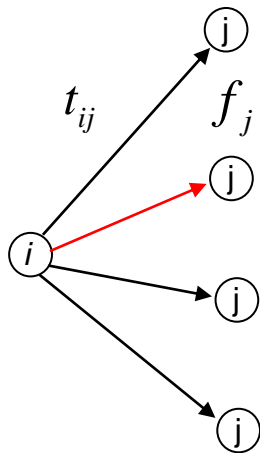


Maximize an integral-type cost

$$J[x_0, \vec{u}] = \int_0^T \phi(x, u) dt$$

vs.

$$J^*(x_0) = \max_u J[x_0, \vec{u}]$$



Minimize (-max) over all possible arcs  $(i, j)$

$$f_i = \min_j \{t_{ij} + f_j\}$$

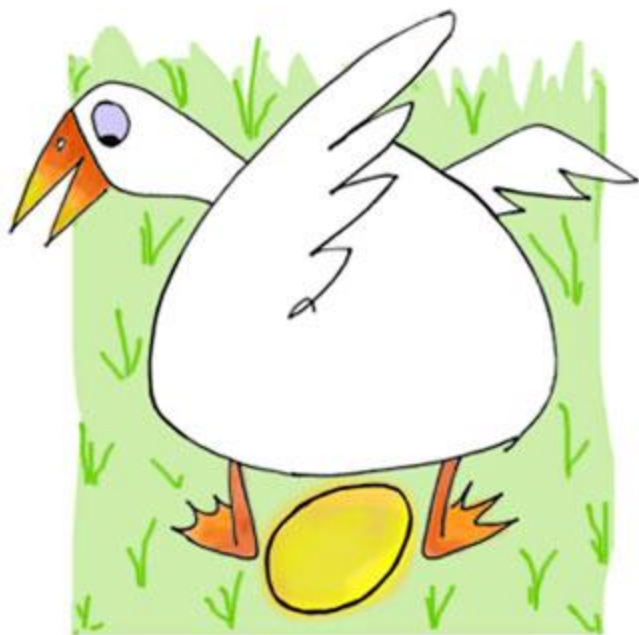
$t_{ij}$  = cost of the directed arc  $(i, j)$

$f_i$  = min travel time from node  $i$  to end



# GOOSE VS. GOLDEN EGGS

ROBOTIC  
SYSTEMS



Revenue produced

$$\phi(x, u)$$

vs.

Value added

$$\frac{d}{dt}[z(t)x(t)] = z\dot{x} + \dot{z}x$$

where

$$z \equiv \frac{dJ^*(x_0)}{dx_0}$$

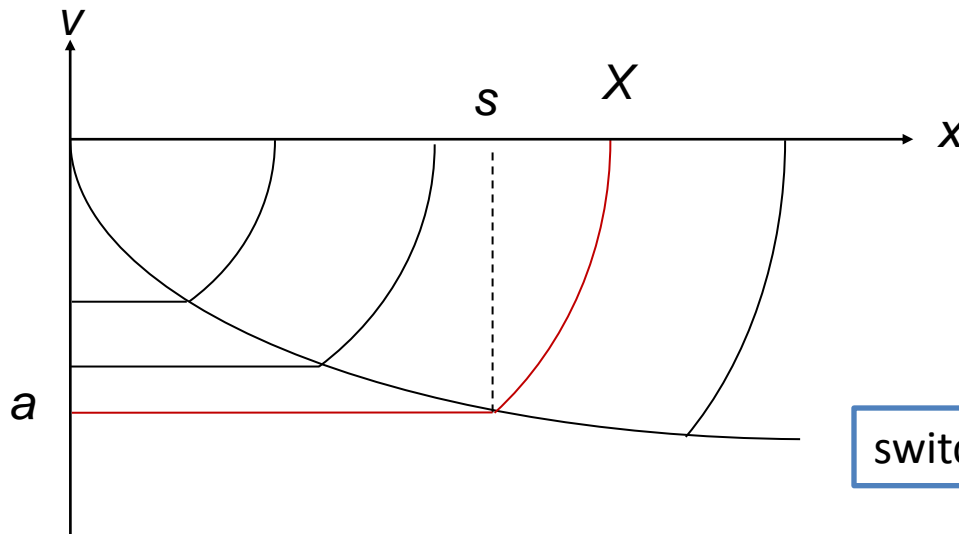
marginal value of state

# SWITCHING CURVE

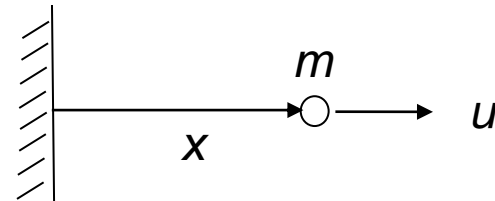
# ROBOTIC SYSTEMS

coasting line,  $a$

$$s = -\frac{m}{k} a^3$$



Positioning Problem



$$J = \int_0^T (k + uv) dt$$

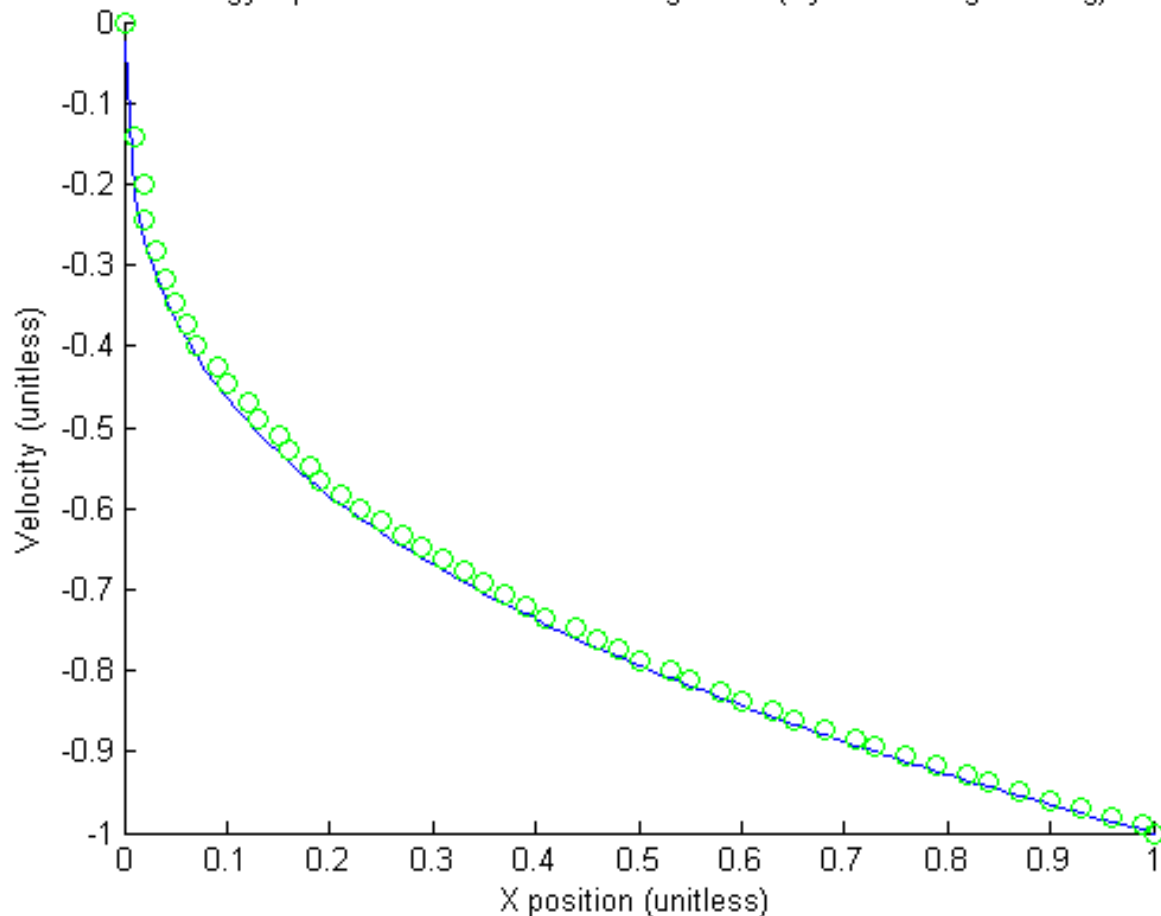
Time + energy cost

switching curve,  $s$

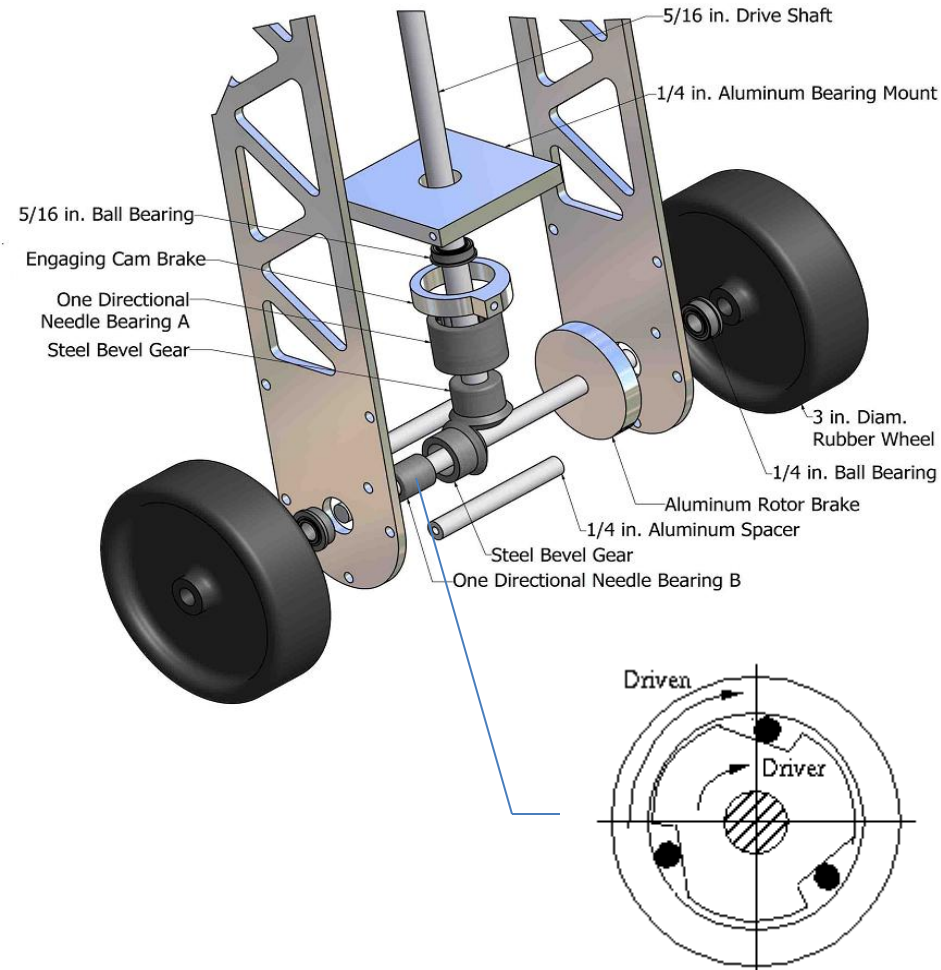
# SWITCHING CURVE

# ROBOTIC SYSTEMS

Energy-Optimal Rocket Car Switching Curve (Dynamic Programming)



- Calculated Data Point
- Theoretical Curve



Overrunning clutch

## Powered Phase

- Clockwise motion engages wheels



Motor CW

## Free Spinning Phase

- Unpowered motor enables this phase



Motor off

## Brake

- Counterclockwise motion engages cam brake



Motor CCW



# FUTURE WORK

## ROBOTIC SYSTEMS



- Game theory approach to disturbances
- Sensor and Acuator uncertainty
- Dissipation



# CONCLUSIONS

## ROBOTIC SYSTEMS



- Unmanned Systems allow for different optimization schemes (e.g. Mobility over Survivability)
- Legged Mobility still requires greater efficiency for real-world applications.
- GREAT PROMISE AND POTENTIAL usually requires GREAT EFFORT AND SACRIFICE to finish the job
- Thanks!